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The traditional house with horizontal opening: a trend towards zero-energy house in the hot, dry climates

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Abstract

The aim of this article is to study by numerical simulation with the TRNSYS-COMIS software, the thermo-aeraulic behavior of a traditional house with a horizontal opening in the central space of the house, and in the city of Kenadsa (southwestern Algeria, hot dry climate). In these regions with hot, dry climates, traditional architecture was developed using empirical knowledge provided by a combination of passive strategies for thermal control, results of a thorough knowledge of weather conditions. The paper presented in the context of this work is related to an attempt to bioclimatic architectural approach, to reduce the energy consumption of heating and cooling of buildings in these areas, while improving thermal comfort. This approach aims to improve the quality of the built environment by developing a new or updated conceptual model, firstly by enhancing local natural resources, and secondly by processing information through scientific tools [1]. Several variants were examined: dimension of the horizontal opening, combination with other openings (of ventilation holes in the parts around the central space, and stairwell) and the effect of building materials used in the building fabric. The proposed model for the simulation of horizontal opening home is validated with an experimental study [2]. The results of this study are presented in the form of hot and cold hours in a year, maximum and minimum indoor comfort temperatures, and frequency of effective ventilation per person as air quality performance indicator in each room.

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Keywords: Horizontal opening, traditional house, ventilation improvement, comfort, hot and dry climate, simplified model

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Introduction

Energy consumption associated with buildings has a significant impact on the environment. Actually, the energy consumption in the building sector is between 40% and 55% of the total demand in the south city in Algeria [1]. Traditional architecture in areas with hot and dry climate has developed an empirical knowledge, particularly oriented towards the realization of comfort in hot weather [3]. The user comfort was provided by a combination of passive strategies for thermal control, results of a thorough knowledge of weather conditions. The traditional architecture provided us excellent techniques which are climate responsive in nature. The principles which were used in traditional buildings can very well be implemented in the modern buildings to improve their energy efficiency and. If these principles are adopted in modern buildings it is possible to build sustainable buildings for the future [2, 4].

In recent years number of studies have been carried out on climate oriented building design to enhance thermal comfort conditions in living space and at the same time to reduce both the embodied and operational energy consumption [5]. Passive design strategies, in particular the application of natural ventilation, are the main techniques to moderate thermal discomfort in buildings [6]. Furthermore, many studies have shown reduced operating costs, better thermal comfort and indoor air quality, to be some of the advantages of the application of natural ventilation in buildings [7, 8]. The patio house with zenithal opening or covered patio house called "ain eddar" in south-west Algeria" is a type of very common traditional houses in the Saharan regions to the Maghreb countries. In those areas, people seek protection from direct sunlight while enjoying the air coming through the zenithal opening.

Horizontal large openings are openings in ceilings and in floors where the open area is in the horizontal plane. A staircase forms a horizontal opening between levels. The special case considered here is the ceiling opening in the patio to the roof. Several studies have examined heat and mass exchange through horizontal openings in buildings, by natural convection [9,10, 11] or by mixed convection [12]. Most of these studies have been performed using small-scale experiments.

Few authors have used the CFD technique to study the airflow through horizontal openings [9, 13] and [12]. In contrast, there is extensive literature showing the evaluation of turbulence models to predict indoor air conditions in single cavities or rooms with different convection regimes [14, 15,16]. The objective of this paper is to study the effect of opening on the zenithal thermoaeraulic behavior of a house situated in a warm, dry climate with the TRNSYS software coupled with COMIS. The zenithal opening is modeled based on the simplified formula [17].

Nomenclature

HC	hot hours according to EN 15251
HTF	cold hours according to EN 15251
% DHC	percentage of reduction of hot hours
% DHTF	percentage of reduction of cold hours
Tmax	maximal temperature
Tmin	minimal temperature

1. Modeling

1.1 Modeling the large opening and general simulation model.

We have used the software TRNSYS coupled with COMIS [19] to conduct our simulations. It uses the following equation (1) to model air flow through horizontal openings. This equation is valid in absence of wind. The actual airflow rate with wind is generally larger.

[17, 18,] and [13] are recent additions to the investigation of air flow through large horizontal openings.

Blomqvist derives a simplified formula for the large opening flowrate as:

$$q_e = C_e.(g'.\sqrt{A})^{0.5} \; (m^3/s) \tag{1}$$

Where A is the area of the opening and C_e is a coefficient determined by experiments. g' is the reduced gravity as:

$$g' = g.\Delta\rho/\rho = g.\Delta T/T \quad (m/s^2) \tag{2}$$

Where g is the gravity field strength (N/kg or m/s^2).

1.2 Location, climate and description of typical house plan

The traditional house selected for study is shown in Fig. 1. It is located in the city of Kenadsa (31°32‘54"N, de 2°25‘36" W), city located 1000km south of Alger at an altitude of 737 m above sea level. The monthly distribution of the air velocity, the temperature, and the relative humidity of the city indicate that most part of the year is outside the comfort zone, except some periods of the months of September, October, March, and April. In November to February, the building may require heating to ensure the comfort of the occupants. The hot season is from May to September. The sun shines more than 3,500 h/year, and the direct solar radiation may reach 800 W/m^2 on a horizontal surface. In summer, the temperature in the shade exceeds 40°C, and the amplitude between day and night is approximately 15°C, whereas the relative humidity remains low, at about 27% [3].

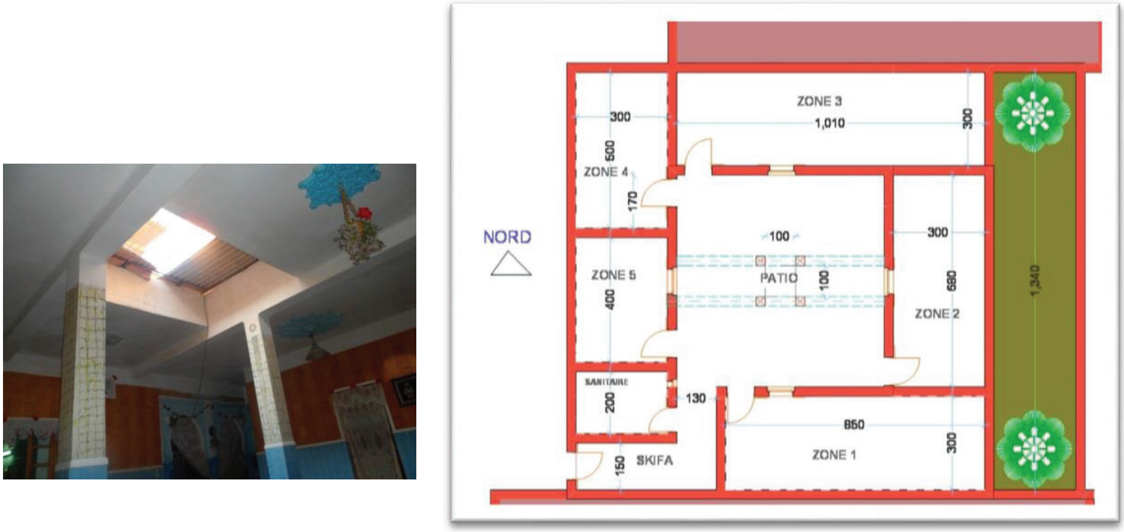


Fig. 1. The traditional house with horizontal opening in the ceiling

1.3 Model validation

To check the reliability of our model, we used the experimental work of Shanthi Priya et al [2]. It was performed on a traditional house in the city of Nagapatinam (10.78 ° N and 79.31 °East, town on the coast of Tamil Nadu in southern India).We took into account the meteorological data obtained by the Meteonorm software. To better control the uncertainties related to the weather data we introduced the values of temperature, relative humidity and air velocity measured by the authors in our weather file in order to make our simulation [1].

Fig.2 shows the evolution of the temperature in the studied house, while Fig.3 shows the results obtained by our simulation. The curve obtained by measurement and the outcome of the simulation evolve in a similar way. On the whole we can say that there is a fair correlation with between the experimental and the simulation results, if we take into account the simplifying assumptions retained due to the geometry the building, the complexity of calculating losses, of the nature of the construction materials of their thermo-physical factors and meteorological data obtained by the Meteonorm software.

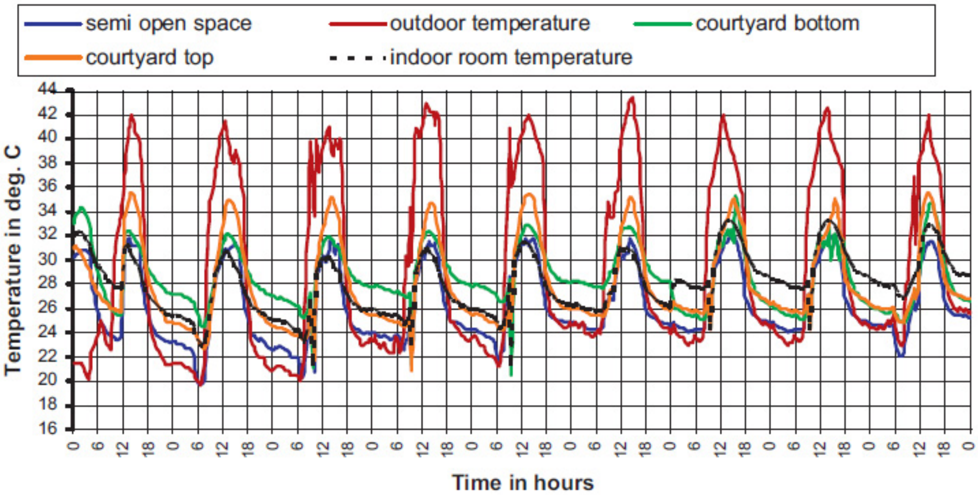


Fig. 2. Measured temperature evolution [2]

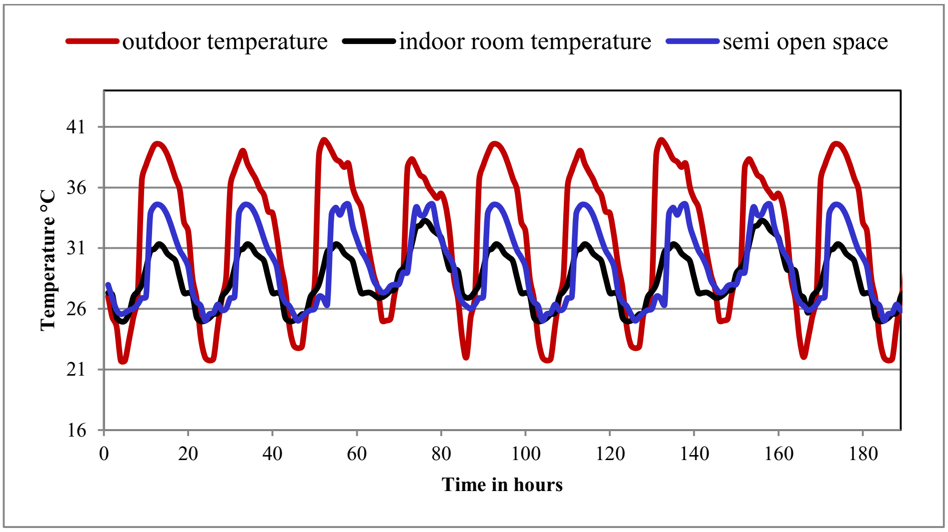


Fig. 3. Evolution of temperature from our simulation

2. Simulation

We assumed that our house shelters 7 persons. We have proposed scenarios for these internal gains: occupancy, use of electrical and cooking appliances [3]. The transmission coefficients of the window, the heat transmission coefficients of window frames, convective coefficients, the solar absorption coefficients of the wall; discharge coefficient, flow coefficient for cracks, have been calculated and introduced into the simulation software [1]. The pressure coefficients Cp were calculated by the Cp Generator tool (WEB http://cpgen.bouw.tno.nl). During this study we have assumed that windows are supposed to be open all day; the doors are open for half the day.

2.1 Influence of structure types on the behavior of the horizontal opening home 'AD'

We have suggested some types of envelopes, composed of the most commonly used materials in the study area, as indicated in Table 1.

Table 1. Description of the modelled envelopes

Wall		Construction materials from the inside to the outside	U W/m²K
Parpaing	External wall	inner plaster 2 cm; parpend 25 cm; cement plaster 2 cm	1.78
	inside wall; Also for the cases P36T7 and P36FIT	inner plaster 2 cm; parpend 10 cm; inner plaster 2 cm	2.31
	Roof	inner plaster 2 cm; hollow flooring blocks 16 cm; Reinforced concrete 4 cm; Sand 2 cm; Cement mortar 2 cm	1.92
	low floor full earth Also for the cases P36T7 and P36FIT	Floor tile 3cm; Cement mortar 2cm; Sand 2cm; Reinforced concrete4 cm; Stone paving 40 cm	1.56
P36T7	External wall Also for P36FIT	Inner plaster 2 cm;Brick 15 cm; Polystyrene 3 cm; Brick 10 cm; cement plaster 2 cm	0.65
	Roof	plaster board 2 cm; air space 20 cm hollow flooring blocks 16 cm; Reinforced concrete 4 cm Waterproofing 1 cm; Sand 2 cm; Cement mortar 2 cm	1.47
P36FIT	Roof	plaster board 2 cm; polystyrene 10 cm hollow flooring blocks 16 cm; Reinforced concrete 4 cm Waterproofing 1 cm; Sand 2 cm	0.31

Table 2 summarizes the results of these envelopes examined in terms of maximum temperature 'Tmax', minimum temperature 'Tmin', hot hours 'HC', cold hours 'HTF' correspond to the numbers of hours during which it is outside the comfort category (III) according to EN 15251[1] and percentage of reduction in hours of discomfort compared to the case Parpaing, which is a common modern way of building and taken as reference. We did not use the PMV and the Fanger model to assess the comfort in these homes, since this model is not valid in naturally ventilated, not conditioned spaces, where the adaptive model better predicts the satisfaction of occupants. In the studied buildings, the surface temperatures are close to the air temperature, so the air temperature is a good approximation of the operative temperature.

Table 2. Maximum and minimum temperatures, annual hours of discomfort and percentage reduction in hours of discomfort compared to the case Parpaing.

Type of Envelope	Tmax °C	Tmin°C	HC	HTF	% DHC/PARPAING	% DHTF/PARPAING
Parpaing	39.17	12.85	2725	2378	-	-
Adobe	36.46	16.70	2481	1162	9%	51%
P36T7	37.90	14.92	2678	1762	2%	25%
P36FIT	35.89	17.31	2390	566	13%	76%

Fig. 4 shows the evolution of the temperature in the zone 1 (Fig. 1) of the AD house for the various examined envelopes. The P36FIT has the lowest temperatures in summer and highest in winter obtained in these simulations, followed by adobe, P36T7 and 'Parpaing' in the last. A reading of Table 2 shows that the effect of these envelopes is significant to reduce the percentage of cold hours, while their effect on the reduction of hot hours is not. The old material "adobe" is nevertheless much more comfortable than the modern "parpaing".

Fig. 5 shows the inter-zonal airflow from the entrance to the patio1. These results are similar for the four envelopes examined during much of the day. In addition, in evening, this inter-zonal airflow varies with the same fluctuations in cases Parpaing, in P36T7 and P36FIT. This latter case presents some distinct difference in the night. The inter-zonal flow for traditional case reaches the highest values, 629 m^3/h compared to other case with a gap of 49 m^3/h compared to the P36FIT cases, 69 m^3/h compared to the case Parpaing, against 58 m^3/h compared to the P36T7 case.

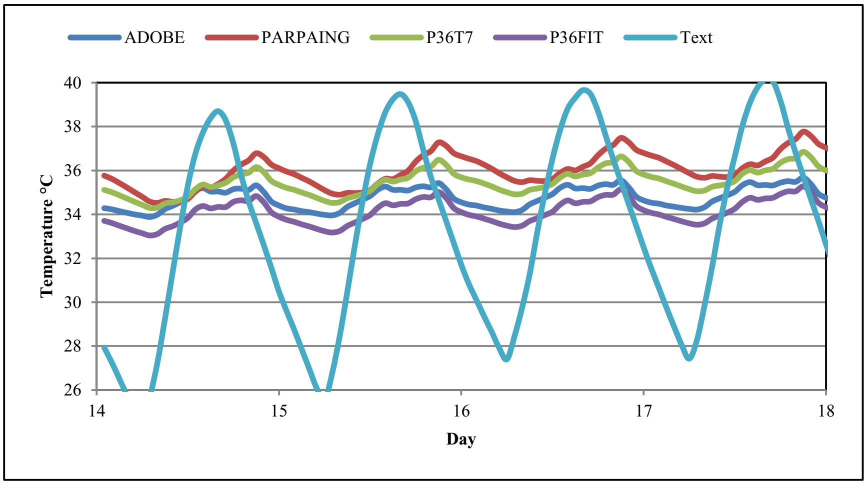


Fig. 4. Temperature of the zone 1 of the simulated home, from 15 to 18 July for the four types of structures

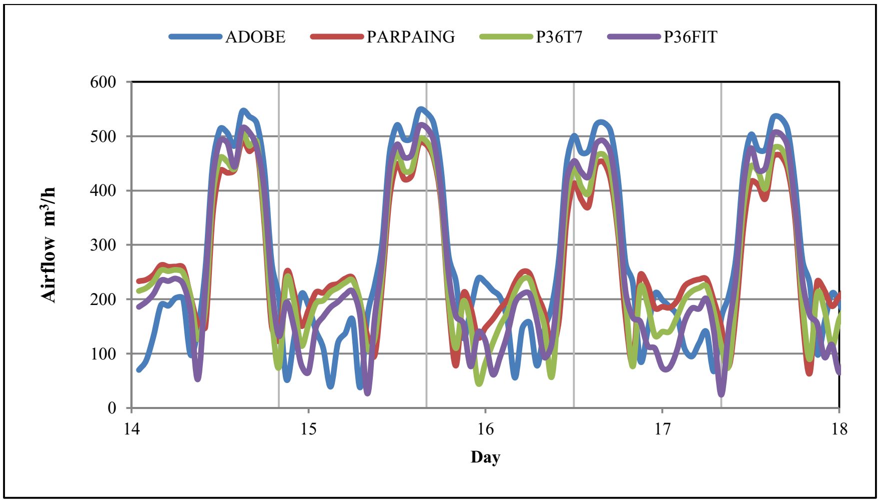


Fig. 5. Airflow from the entrance to zone 1 of the house from 15 to 18 July for the four types of structures

2.2 Influence of the dimensions of the zenithal opening

In this part of our work we will examine the impact of the dimensions of the zenithal opening on the thermal behavior of the simulated house. We selected six dimensions that may be encountered in this type of house in the study area. The results are shown for zone 1, in Table 3.

Table 3. Maximum and minimum temperatures, annual hours of discomfort and percentage reduction in hours of discomfort compared to the square opening 1 m aside.

dimensions of the horizontal opening (meter)	Tmax °C	Tmin°C	HC	HTF	% DHC/1X1	% DHTF/1X1
1 x 1	39.17	12.85	2725	2378	-	-
1.5 x 1	39.07	12.7	2643	2424	3.01	-1.93
1 x 2	38.97	12.51	2575	2483	5.50	-4.42
1.5 x 1.5	38.91	12.38	2542	2525	6.72	-6.18
1.5 x 2	38.79	12.2	2480	2584	8.99	-8.66
2 x 2	38.62	12.14	2403	2659	11.82	-11.82

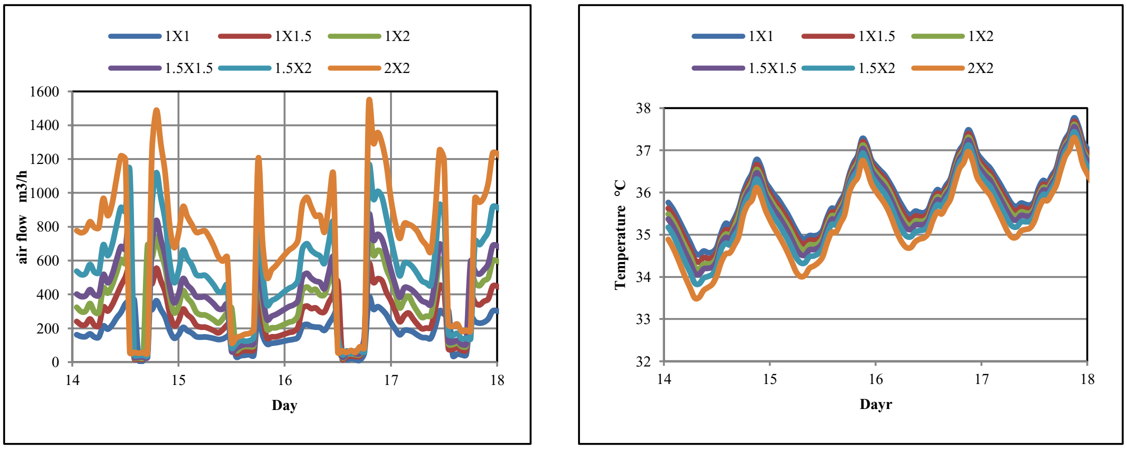


Fig. 6. On the left: Outside air flow in the entrance, on the right: Temperature in zone 1, for different sizes of horizontal opening from the 14 to 17 July.

As expected, the outside air flow in the entrance increases with the opening area. It is a little more sensitive in summer than in winter. This contributes to a slight reduction of hours of discomfort in summer and increases the number hours of discomfort in winter as clearly illustrated in Fig. 6. On this figure we see that the case 1.5 x 1.5 m² generated hot and cold hours very close in value, while the difference between those two hours discomfort becomes more evident with the increase and decrease of the area of AD from this case where the hot hours become more numerous than the cold hours. We can observe in Table 3 that the maximum temperature reached in the various areas of the house decreases very slightly with the increase of the surface of the Zenithal opening where a difference of 0.55 ° C is found between the two case 1X1 and 2X2 m in the zone Z1. At the scale of a day, we see in Figure 6 that the temperature is reduced compared to the reference case 1X1. An increase in the amplitude of Z1 temperatures is also observed with the increase in the area of the Zenithal opening. This amplitude is 3.97 ° C for the case 2X2 m² against 2.11 ° C for the case 1X1m². This is due to the potential of the night ventilation that becomes more important with increasing dimension of AD. The temperatures do not drop below 31.47 ° C in July and August, whatever the size of the Zenithal opening.

On Fig. 7 we have plotted the frequency curves of the effective ventilation in summer, per person for one year in the zone 1. This figure, effective ventilation, tells how much air is available to evacuate the pollutants generated by a given source (an inhabitant is this case) in a zone of the house. We see that the effect of the opening size is more visible on the effective ventilation. . The most frequent efficient flow rate is 20 kg/h and person for the small 1 m² opening, while it is 40 kg/h and person with the large 1.5 x 2 and 2 x 2 m opening. So the air, on average, will be "cleaner" with a large opening. We see nevertheless that the actual ventilation does not fall below 4 kg/ (h person) for the two smallest openings and 8 kg / (h person) for the other ones, which shows that the patio is sufficiently ventilated.

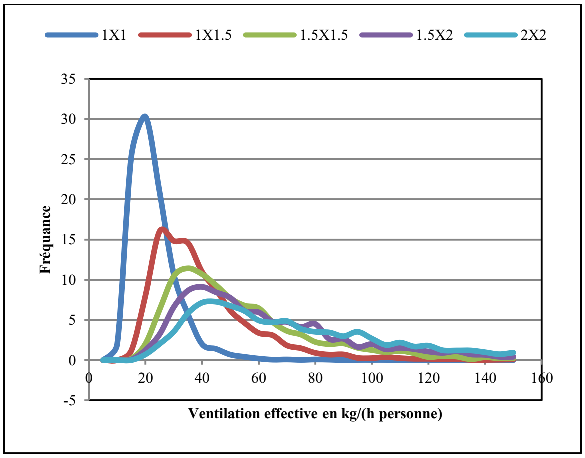


Fig. 7. Frequency of effective ventilation per person in the zone 1 summer for different dimensions of horizontal opening

2.3 Influence of air wells

This type of house is characterized by the presence of several air sources:

- the stairs, which lead to the terrace, a place where the ancient inhabitants sleep in the open during hot night in the summer),
- the chicane entrance (called "skifa") that aims to preserve the privacy of the home and
- ventilation orifices in the rooms surrounding the center of the house.

In this part of our work, we made a comparison between the following four configurations:

- "Sans" : the house with Parpaings without ventilation opening or stairwell and holding the entrance door permanently closed;
- "Ov" : the house with ventilation orifices and without stairwell, and maintaining the entrance door permanently closed;
- "Skifa" the entrance: the house without ventilation opening or stairwell and with an opening scenario for the entrance door;
- "Escalier": house with a staircase open to the terrace on the roof.
- "AD1 1.5x2": the house with a zenithal opening of dimension of 1.5 x 2m².

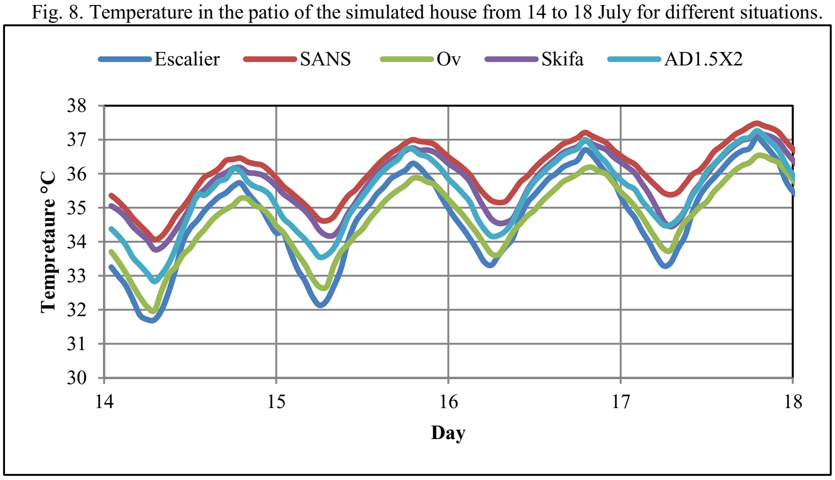
We retained the opening scenarios shown in Table 4.

Table 4. openings scenarios of the apertures in case of presence of stairs, ventilation openings.

	Windows		**Doors**		**AD**		**External door of skifa**		**Orifices of aeration**		**Door of the stairwell**	
	opened	**closed**	**opened**	**closed**	**opened**	**closed**	**opened**	**closed**	**opened**	**closed**	**opened**	**closed**
0Summer	20-to 07 50% and 07-20 100%	20-to 07 50%	22-7 50% and 7-13 100% 13-18 50% and 18-22 100%	22-7 to 50% and 7-13to 100%	0-24		6-10 and 18-22	10-18 and 22-6	18-11	11-18	18-10	10-18
Winter								0-24				

Fig. 8 shows a plot of the temperature of the patio for these configurations. This zone, which is the heart of the house, is the area of the air passage before it joins the other areas. This figure demonstrates the impact of the orifices in lowering of the temperature in this area for a good strategy of door openings and interior windows, which indicates a good exchange of air between this area and the different rooms equipped with these external ventilation links. Among these configurations the opening of the gat stairwell presents the greatest potential for night ventilation cooling, with an amplitude of 4° C in July. The case with ventilation openings also has good potential for night ventilation cooling. Opening the entrance door helps to improve thermal comfort in he center of the house. It leads sometimes to low temperatures observed from 6 am opening time of the door compared with the case of AD opening of 1.5x2m². In hot arid climates, this is a popular way of cooling down the building during the night.

Fig. 8. Temperature in the patio of the simulated house from 14 to 18 July for different situations.



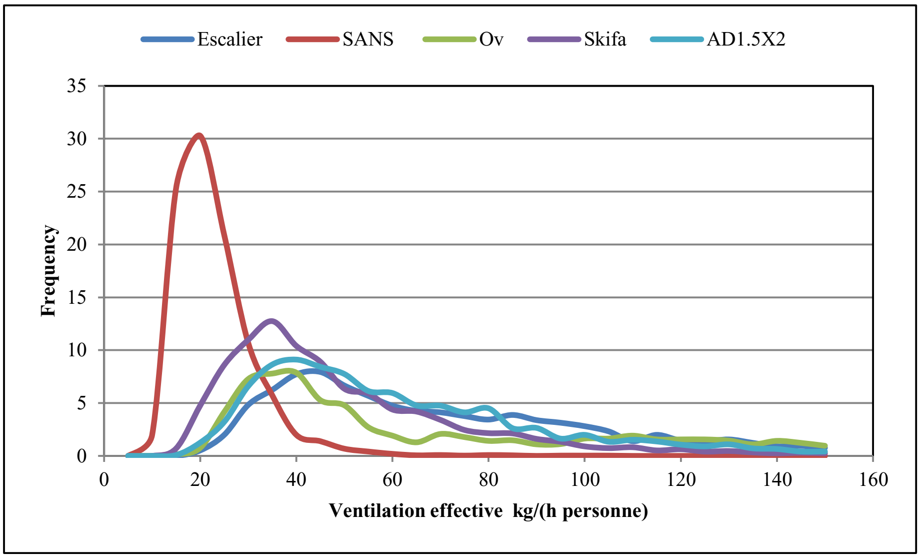


Fig. 9. Frequency curve of effective ventilation per person in the patio for the different situations studied.

Fig. 9 compares the frequency distributions of effective ventilation in the zone 1 to the five situations examined. It appears that effective ventilation is the largest when opening the door to the stairwell and the ventilation orifices. The increase in size of the zenithal opening gave very similar results as the stairs and ventilation openings. Opening the entrance door seems to be quite an effective way to create good ventilation and air quality, the air entering through this door goes to other areas via the covered patio. However, its opening is limited by safety conditions. However, we can say that opening the stairwell combines the wind effect and the temperature effect, it allows good air circulation in the house.

Conclusions

In this work, we attempted to examine, through multiple simulations of the thermal behavior of a typical, traditional Mahgrebian house and the impact of different architectural elements of this type of houses, namely: size of the horizontal opening over the covered patio, stairwell to the terrace, "skifa" entrance, and ventilation openings between rooms and the patio.

Traditional building materials like adobe gave the most interesting results, showing the adaptation of this type of habitat to the local climate. On the other hand, the addition of insulation in exterior walls and in the roof with plaster false ceiling and a 20cm thick air gap (P36T7 case) contributed to improved comfort compared to the case cinderblock but remains less important than if we introduce a strong insulation in the roof.

The impact of the opening of the stairs (when present) in this type of home presents fairly similar results than opening the entrance door but more important and safer!

Indeed, in the majority of this type of houses with overhead opening larger than 1 m², occupants proceed to partly or totally closing the overhead opening by blankets or wooden plate during the hours of the afternoon to avoid sunlight coming in through the opening. The vents between the rooms and the patio have a direct effect on reducing hot hours per night ventilation. While the combined effect of these three vents, ventilation by opening the door to the stairwell and the entrance door significantly contribute to the improvement of the thermal comfort of the house and its ventilation. Good management of ventilation times for these architectural elements form the basis of this type of habitat in the area under study, since it is recommended to achieve good comfort while making sure not to spoil the quality of the indoor air and the security of the home.

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